

EXECUTIVE SUMMARY

FINAL REPORT TO THE
CALIFORNIA AIR RESOURCES BOARD

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STUDY OF PARTICULATE EPISODES AT MONO LAKE

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Executive Summary

The goals of this study were to --

1. Evaluate the frequency and severity of elevated dust (Total Suspended Particulates, TSP) episodes in the vicinity of Mono Lake,
2. Understand the physical and chemical nature of the particulate matter,
3. Determine the sources of the particulates and the suspension mechanisms responsible for elevated dust levels,
4. Establish the connection between particulate levels and local meteorology.

During the course of the work, adequate progress was made on these primary goals to allow us to develop a computer model to--

5. Predict changes in dust episodes as a function of the water level in Mono Lake, and
6. Discuss the nature and effectiveness of possible mitigation measures.

In order to achieve these goals, extensive measurements were made of particulate matter at two locations near Mono Lake that represent generally upwind and downwind sites with regard to strong (dust raising) wind conditions. Continuous 24 hour and 8 hour size-selective samplers were used for 8 months at these sites. Additionally, battery-and solar-powered units were developed at Davis and deployed during dust events to measure the spatial extent and magnitude of the dust clouds. Meteorological data were taken from monitors at the lake, and an intensive meteorological study was made at the Simis ranch in August and September, 1982. Elemental analyses were made of the particles by size

category, and elemental and chemical studies were also made of local soils and playa materials. Data were also derived from the Great Basin Valleys APCD, our participation in the Lands Commission Owens Lake study, as well as photographs from the Los Angeles Department of Water and Power, the Mono Lake Committee, and our own work. The interpretation included in this study also draws upon the results of our two prior studies for the ARB at Owens and Mono Lakes. A semi-empirical computer model was developed and calibrated using dust levels measured at both lakes and at sites up to 75 miles downwind.

1. Frequency and severity of dust episodes

Two multi-year records of dust episodes near Mono Lake have been generated--data on total suspended particulates (TSP) taken with standard Hi-Vol samplers by The Great Basin Valley APCD, and a set of daily colored photographs taken by the Los Angeles Department of Water and Power.

Great Basin Valley's APCD (GBVAPCD) Particulate Monitoring.

Table 1 shows the results of standard total suspended particulate measurements in the period from 1979 to 1983 at two sites near Mono Lake (Lee Vining and Binderup/Simis) and one near Owens Lake (Keeler). The TSP results show that particulate air quality at Mono Lake is among the very best in California when non-dust conditions occur; yet among the very worst during the relatively infrequent severe dust episodes. Sites downwind of Owens Lake (Keeler) and Mono Lake (Binderup/Simis) approximate or exceed the federal emergency level of $1000 \mu\text{g}/\text{m}^3$ on 5% of all days-- $833 \mu\text{g}/\text{m}^3$ at Mono and $1198 \mu\text{g}/\text{m}^3$ at Keeler in the period 1979 - 1982. In most years, these two sites had the highest measured 24-hour TSP levels in California. Geometrical mean TSP values are not high, however, since TSP levels are very low in the far more common non-episode conditions.

FIGURE 1 Mean episode TSP profiles (24 hour average)
Mono-Owens Davis Dust Model (Highest 5% of all days)

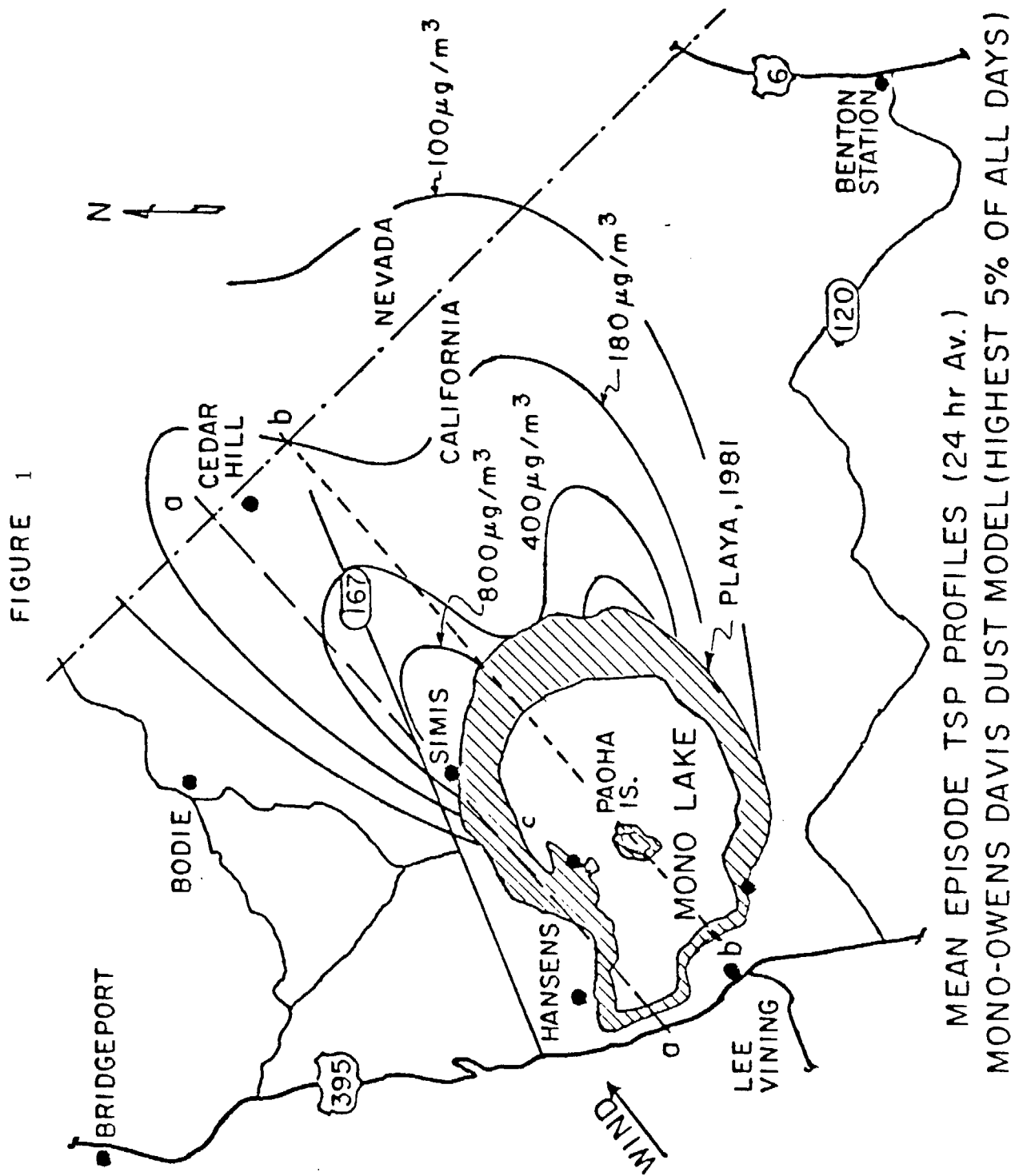


Table 1 Frequency and severity of occurrence of dust episodes near Mono and Owens Lakes, 1979-1983 (1)

	Mono Lake		Owens Lake
	Lee Vining (upwind)	Binderup/Simis (downwind)	Keeler (downwind)
1. Worst day measured 1979 to 1983	131 $\mu\text{g}/\text{m}^3$	3300 $\mu\text{g}/\text{m}^3$ *	3295 $\mu\text{g}/\text{m}^3$
2. Worst 1.3% of all days, 1979 to 1983	108 $\mu\text{g}/\text{m}^3$	1825 $\mu\text{g}/\text{m}^3$	2196 $\mu\text{g}/\text{m}^3$
3. Worst 5% of all days, 1979 to 1983	75 $\mu\text{g}/\text{m}^3$	833 $\mu\text{g}/\text{m}^3$	1198 $\mu\text{g}/\text{m}^3$
4. Worst 11% of all days, 1979 to 1983	58 $\mu\text{g}/\text{m}^3$	530 $\mu\text{g}/\text{m}^3$	630 $\mu\text{g}/\text{m}^3$
5. Remaining 89% of all days, 1979 to 1983	22 $\mu\text{g}/\text{m}^3$	17 $\mu\text{g}/\text{m}^3$	26 $\mu\text{g}/\text{m}^3$
Sampling days	197	78	327

(1) Based upon all 24-hour days measured by Great Basin Valley District Hi-Volume samplers, generally operated on a one-day-in-six pattern

* Measured by Davis Sampler and corrected to equivalent Hi-Volume value. Estimated uncertainty, $\pm 400 \mu\text{g}/\text{m}^3$. Not included in statistical summaries since it was not taken randomly

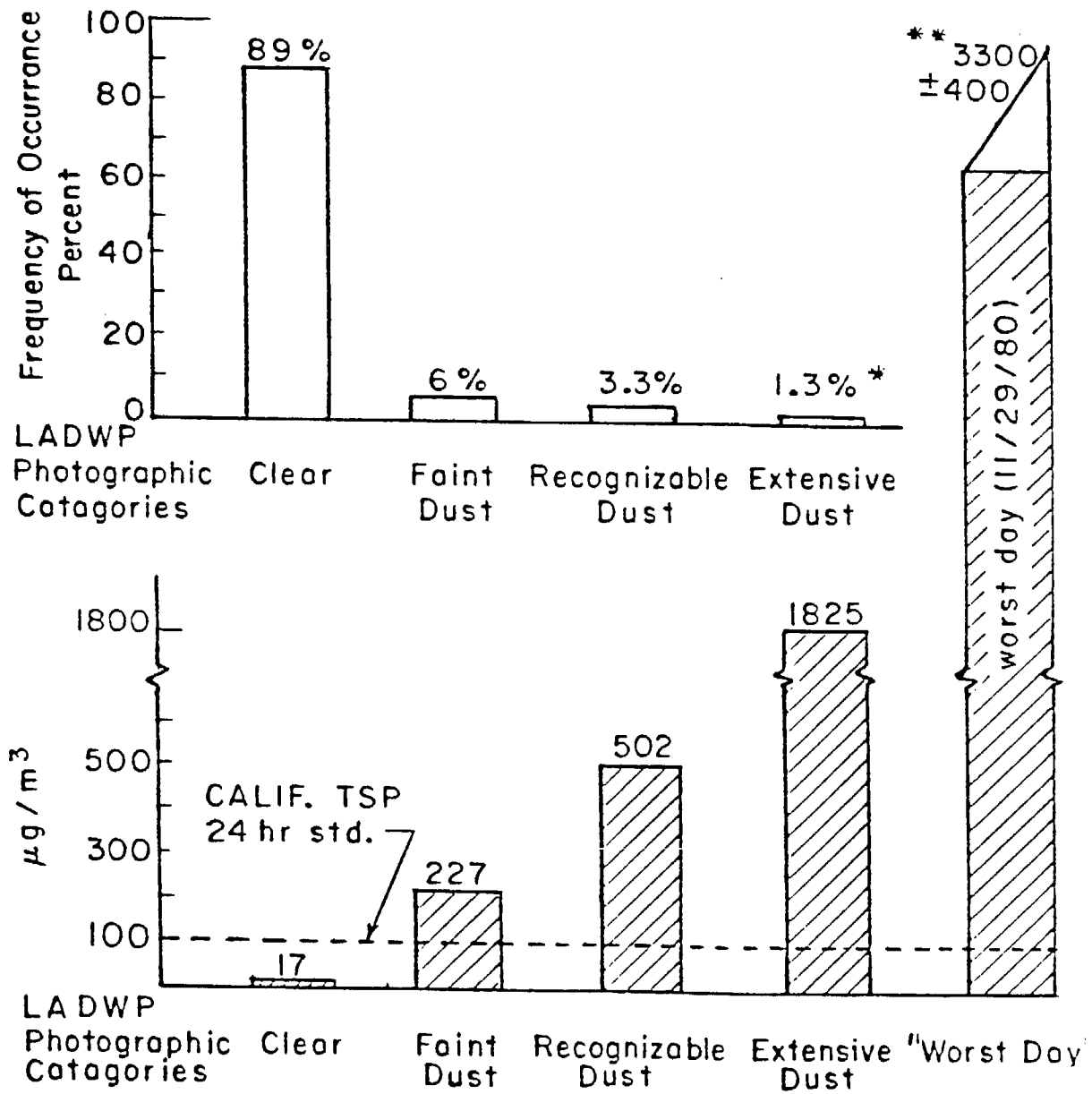
Los Angeles Department of Water and Power photographic study. An extensive photographic record of Mono Lake, taken daily at a site near Lee Vining, has been generated by the Los Angeles Department of Water and Power (LADWP) for the period from February 22, 1980 through February 21, 1984. Of the photographs taken, 1,412 were of adequate quality to allow the LADWP to classify them into four categories:

Clear	(89 % of all photos)
Faint Dust	(6 % of all photos)
Recognizable Dust	(3.3% of all photos)
Extensive Dust	(1.3% of all photos)

Correspondence between TSP and photographic categories. The correspondence between these two statistically extensive data sets is given in Table 2. The district TSP measurements were made only on the standard one-day-in-six schedule, but adequate data exist to match the LADWP percentages of occurrence for each visual dust category to district TSP measurements. These are given in Table 2, and graphed in Figure 1.

The "Clear" category, occurring 89% of all days, averages $17 \mu\text{g}/\text{m}^3$ TSP, a level as low as the cleanest sites in California. The "Faint Dust" category, occurring 6% of all days, averaged $227 \mu\text{g}/\text{m}^3$ TSP, or more than twice the state 24-hour TSP standard. The "Recognizable Dust" category, occurring 3.3% of all days, averaged $502 \mu\text{g}/\text{m}^3$ TSP, or five times the state 24-hour TSP standard. Finally, the "Extensive Dust" category, occurring 1.3% of all days, corresponded to $1825 \mu\text{g}/\text{m}^3$ TSP. The qualitatively greatest dust event of the past three years, November 29, 1980, included in the LADWP photographic survey, was not sampled by the district Hi-Vol, but our measurements gave an approximate value of $3300 \mu\text{g}/\text{m}^3 \pm 400 \mu\text{g}/\text{m}^3$ for that day.

FIGURE 2 Correspondence between photographic record of dust episodes (LADWP) and total suspended particulate measurements (GBVAPCD)



* 18 days in 4 years

** Hi-vol equivalent from Davis sampler. Not included in statistical record since district sampler did not operate on this day.

Since the "Recognizable Dust" and "Extensive Dust" categories of the LADWP add up to 4.6% of all days, they can be compared directly to the "Highest 5% of all days" category of Table 1, giving an average value of 833 $\mu\text{g}/\text{m}^3$ TSP value in these conditions. The corresponding TSP value for the highest 5% of days at Owens Lake was 1198 $\mu\text{g}/\text{m}^3$.

TABLE 2 Correspondence between photographic observations (LADWP) and dust (GBVAPCD) at Mono Lake

Los Angeles Dept. of Water and Power Photographic Categories	Frequency of Occurance	<u>TSP Mass Loadings</u>	
		Mono/Simis	Keeler*
Extensive dust [Worst]	1.3%	1825 $\mu\text{g}/\text{m}^3$	2196 $\mu\text{g}/\text{m}^3$
Recognizable dust [Next]	3.3%	502 $\mu\text{g}/\text{m}^3$	836 $\mu\text{g}/\text{m}^3$
Faint dust [Next]	6.0%	227 $\mu\text{g}/\text{m}^3$	269 $\mu\text{g}/\text{m}^3$
Clear	<u>89.4%</u>	17 $\mu\text{g}/\text{m}^3$	26 $\mu\text{g}/\text{m}^3$
	= 100.0%		
(Sum of Extensive and Recognizable categories)	4.6%	833 $\mu\text{g}/\text{m}^3$	1198 $\mu\text{g}/\text{m}^3$
(Sum of Extensive, Recognizable and Faint categories)	10.6%	530 $\mu\text{g}/\text{m}^3$	630 $\mu\text{g}/\text{m}^3$

* For comparison purposes; No equivalent photographic evidence is available at Keeler.

2. Physical and chemical nature of particulate matter

Data on particulate size generated in this study show that fine particulate matter, below $2.5\text{ }\mu\text{m}$ diameter, usually reaches only very modest levels, even in dust episodes. Fine mass at all sites near Mono Lake is dominated by sulfur-containing particles at levels similar to other Sierra sites, $0.48 \pm 0.03\text{ }\mu\text{g}/\text{m}^3$ of sulfur or about $1.5\text{ }\mu\text{g}/\text{m}^3$ of sulfate (six month summer average of four sites). Little or no lake impact is seen in this fine mode. Coarse particle modes during non-episode conditions occur at low levels, and are dominated by local soils with some persistent but minor contribution from lake bed sources. Particles of the dust episodes, which in this study are between 2.5 and $15\text{ }\mu\text{m}$ diameter and are thus inhalable, are dominated by materials from the lake playa areas, not the non-lake soils in the surrounding area. This conclusion is supported by:

1. Photographic evidence from the LADWP, Mono Lake Committee, our photographs, and the geological literature
2. Upwind-downwind ratios, normally between Lee Vining and eastern sites of the basin (Binderup/Simis) but occasionally the inverse, showing essentially all of the dust episodes are dominated by lake bed sources, with little transport into the basin or local soil impact
3. Size and compositional studies of dust episodes, which set upper limits to the non lake bed sources in the episodes
4. Meteorologically correlated particulate sampling, showing the short term generation of dust particles from playas.

A summary of the photographs is included in Appendix B of the full report. The following table gives all simultaneously measured upwind-downwind ratios at Mono Lake, $\text{TSP} > 120\text{ }\mu\text{g}/\text{m}^3$.

Total Suspended Particulates

Date	<u>Lee Vining</u>	<u>Binderup/Simis</u>
August 19, 1979	17 $\mu\text{g}/\text{m}^3$	266 $\mu\text{g}/\text{m}^3$
October 24, 1979	15 $\mu\text{g}/\text{m}^3$	193 $\mu\text{g}/\text{m}^3$
November 17, 1979	7 $\mu\text{g}/\text{m}^3$	481 $\mu\text{g}/\text{m}^3$
June 2, 1980	1 $\mu\text{g}/\text{m}^3$	136 $\mu\text{g}/\text{m}^3$
November 29, 1980	6 $\mu\text{g}/\text{m}^3$	3300 \pm 400* $\mu\text{g}/\text{m}^3$

But, also notice --

March 28, 1980	131 $\mu\text{g}/\text{m}^3$	17 $\mu\text{g}/\text{m}^3$
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* estimated from non Hi-Vol samplers and model

Studies of intensive episodes included measurements of both composition and downwind mass levels out to Cedar Hill, 8 miles northeast of Mono Lake and close to the Nevada state line. Studies were made of the possible chemical states of the dominant alkaline salts, including sodium sulfates, gypsum, trona, sylvite, and other minerals similar to those reported earlier of Owens Lake and Deep Springs Lake.

A number of potentially toxic elements were seen during the study, in both playa materials and dust episodes. These include selenium, arsenic, mercury, and lead. A special study was focused on arsenic content. Levels of arsenic in the playas were found in four separate studies to be in the range of 20 to 60 ppm, while dust episodes had measured arsenic levels of (30 ± 10) ng/m^3 at Keeler and (22 ± 10) ng/m^3 at Mono Lake. The precise chemical state of the arsenic in the highly basic alkaline salts was not determined.

3. Sources and suspension mechanisms for dust episodes

The dust problem involves the combination of an elevated wind threshold (25-30 mph) characteristic of large sand particles, and observations of fine dust particles (5-15 μm) which, if lying on the ground, could be resuspended at wind velocities of only a few mph. A hypothesis was developed based on earlier work by this group and wind tunnel studies by Dale Gillett at Owens and other dry saline lake beds. It was found that the efflorescent crusts that grow above the briney mud, although fragile, are very hard to resuspend—even with strong winds. The answer appears to lie in the key role of saltating large particles that bounce along the ground breaking off and grinding up these fragile efflorescent crusts. This hypothesis is strongly supported by measurements made for the California Lands Commission and its subcontractor (Westec) on Owens Lake. During three severe 6-hour episodes, measurements of TSP at 2 meters above the lake averaged about 40,000 $\mu\text{g}/\text{m}^3$. The composition had far more coarse sand and large broken salt particles than measurements made away from the lake bed at Keeler and Lone Pine.

Thus, the mechanism for initiating a dust episode requires five conditions be met:

1. Wind velocity above some threshold, about 25 mph, generally associated with passage of a synoptic weather front and sudden change of barometric pressure;
2. High wind shear at the surface due to lack of obstructions and terrain relief;
3. Adequate fetch across the playas, since photographs show that it takes between 1 and 2 miles before dust events initiate;
4. Coarse particles must be present to grind up the efflorescent salt crust which, by itself, can hardly be resuspended at any wind speed, and
5. The efflorescent crust itself, easily broken into the 5 to 20 micron particles (alkaline-salt) observed in the dust (salt) plumes.

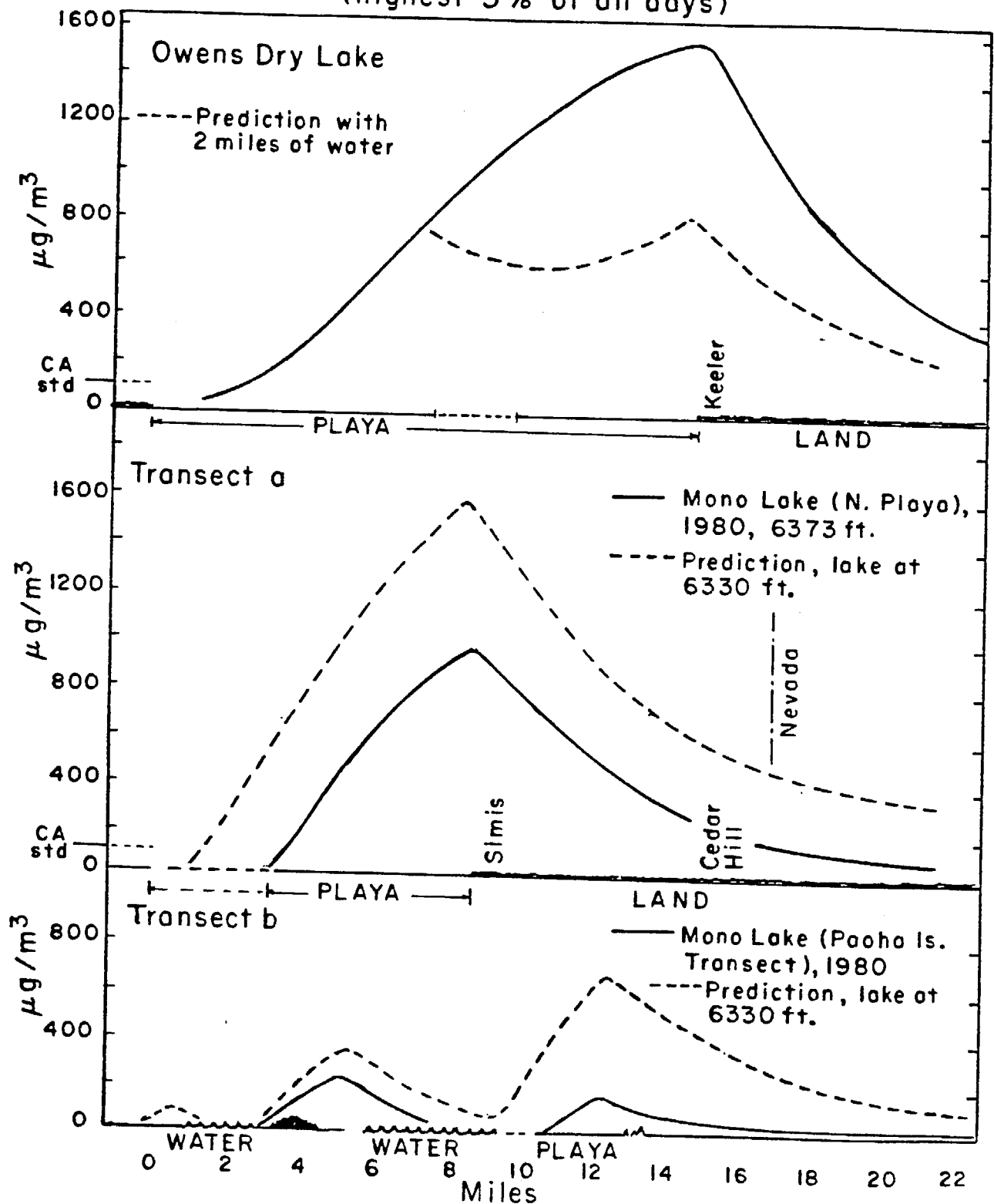
4. Connection between particulate levels and local meteorology

No strong association between synoptic weather and Mono dust episodes was found, other than they generally occur in strong westerly winds following a sharp drop in barometric pressure after passage of a front. More measurements are needed to determine the wind threshold for initiating dust events at Mono Lake; it appears to be slightly higher than observed at Owens Lake, or around 25 mph. A micrometeorological intensive study documented the low zero-plane displacement parameter Z_0 , leading to high wind shear across the playas.

5. Computer modeling of Changes in dust episodes as a function of water level

A computer model was developed using all the above information in order to predict dust levels at the lake and up to 150 miles downwind. This model, the Mono-Owens Davis Dust Model (MODDM), was applied to both Owens and Mono Lakes, and includes predictions of TSP values as a function of wind direction, length of playa, fetch, and lake elevation. This model was based on the known physics of blowing sand, calibrated in TSP magnitude against district Hi-Vol readings for the 5% highest days, and calibrated for fall-off of concentrations versus distance on four fully measured alkaline/saline dust events from Owens Lake to Bishop (75 miles) between 1979 and 1982. Thus, all predictions are based on data taken under similar or identical circumstances to those observed at Mono Lake. The predicted TSP mass contours for the worst 5% of dust episodes are shown in Figure 1, using the 1981 lake level. Using the stabilization level with diversions of 6330 feet, the predicted values for the 5% worst days rise by 180% (north playa), 480%, (Paoha Island transect), and 1090% (south playa), due to the rapidly increasing linear fetches and the decreasing water particulate sinks. (Figure 3)

Figure #3
Suspended Particulate Matter (TSP) $\mu\text{g}/\text{m}^3$
(highest 5% of all days)



6. Nature and effectiveness of possible mitigation measures

Since the causes of the dust episodes near Mono and Owens lake are clearly associated with the rapid lowering of lake levels, the most effective mitigation measures would be a raising of lake levels to cover playa areas. This, in fact, occurred to some degree at Mono Lake in 1982-1983, when the lake rose about nine feet. Owens Lake had very bad dust levels in 1982, worse than Mono, while in 1980, when Mono Lake was at its historically low level, Mono dust events were worse than Owens. Perhaps too few events were recorded to give statistical weight to these results, but it is in semiquantitative agreement with the model, since the higher 1982 Mono Lake level flooded a depression (marked "C" on Figure 1) and cut the major Mono dust fetch in two. For sake of argument, the MODDM model was also run for Owens, with two miles of water placed $\frac{2}{3}$ of the way across the lake. Predicted dust levels at Keeler decrease by a factor of 2 for the 5% highest days. Emplacement of this water barrier may not be as difficult as it seems, if the laser-leveling techniques used in Northern California rice fields would be applied to making a series of shallow, alkaline ponds across Owens. The recent wet years have done almost half the job already.

Of the five conditions required for a dust episode, condition 1 (synoptic weather) is impossible to control; condition 5 (efflorescent crust) is very hard to control, since the wet alkaline muds beneath the surface would defeat all but the most expensive "paving" efforts, while fully drying the lake, an expensive proposition, would make matters far worse for decades before mitigation might occur, based on the Owens experience. Likewise, condition 3 (fetch) is hard to control except by adding water to the lake. Condition 2 (wind shear) can be lowered by placing obstructions such as snow fences, while condition 4 (coarse particles) could be controlled by either sand traps (fences or water barriers, or other such mechanisms) or by controlling coarse particle sources at the edge of the playas. Controlling coarse particles at Mono would be fairly easy if the lake is high since the fetches are long but narrow.

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